2. Science and Exploration Rationale

2.1 Introduction

Mars is an intriguing and exciting planet with many adventures and discoveries awaiting planetary explorers. But before we go, we must provide the tools the explorers will use, anticipate as much as possible the situations they will encounter, and prepare them for the unexpected. For the first time in a space exploration mission, it will be up to the crew and supporting personnel on Earth to create specific activities as the mission progresses and discoveries are made. The length of time spent on the martian surface, as presented in the Reference Mission, will preclude development of the detailed, highly choreographed mission plans typical of today's space missions. The crew will have general goals and objectives to meet within their other time constraints (for example, exercise for health maintenance, regular medical checks, routine systems maintenance, etc.). Based on knowledge gained from precursor robotic missions, the crew will land in an area that has a high probability of satisfying the pre-set mission objectives. However, due to the extended communications time lag between Earth and Mars, the crews and their systems must be able to accomplish objectives in a highly autonomous manner with only general support from Earth. From the rationale generated by the Mars Study Team for sending human crews to Mars, goals and objectives are derived to provide guidance for the exploration crews during their extended stay on the martian surface. This section will discuss that Study Team rationale.

2.2 The "Why Mars" Workshop

In August 1992, a workshop was held at the Lunar and Planetary Institute in Houston, Texas, to address the "whys" of Mars exploration. This workshop brought together a group of experts (listed in Table 2-1) familiar with the key issues and past efforts associated with piloted Mars missions in an effort to provide the top-level rationale and requirements from which the Mars exploration program could be built (Duke and Budden, 1992). This group was asked to generate three key products: a Mars mission rationale, Mars exploration objectives, and a list of key issues and constraints, to be used by the Mars Study Team (members listed in Table 2-2) to define the technical details of a Reference Mission. The workshop attendees identified six major elements of the rationale for a Mars exploration program.

Table 2-1 Mars Exploration Consultant Team

Dr. David Black Director Lunar and Planetary Institute Houston, Texas	Dr. George Morgenthaler University of Colorado Boulder, Colorado
Dr. Michael Carr U.S. Geological Survey Menlo Park, California	Dr. Robert Moser Chama, New Mexico
Dr. Ron Greeley Dept. of Geology Arizona State University Tempe, Arizona	Dr. Bruce Murray California Institute of Technology Pasadena, California
Dr. Noel Hinners Lockheed Martin Denver, Colorado	Mr. John Niehoff Science Applications International Corporation Schaumburg, Illinois
Dr. Joseph Kerwin Skylab Astronaut Lockheed Martin Houston, Texas	Dr. Carl Sagan Center for Radiophysics and Space Research Cornell University Ithica, New York
Mr. Gentry Lee Frisco, Texas	Dr. Harrison Schmitt Apollo 17 Astronaut Albuquerque, New Mexico
Dr. Roger Malina Center for EUV Astrophysics University of California Berkeley, California	Dr. Steven Squyers Cornell University Ithica, New York
Dr. Christopher McKay NASA Ames Research Center Moffett Field, California	Mr. Gordon Woodcock Boeing Defense and Space Group Huntsville, Alabama

Table 2-2 Mars Study Team

Dr. Geoff Briggs NASA Ames Research Center Moffett Field, California	Mr. Kent Joosten NASA Johnson Space Center Houston, Texas
Ms. Jeri Brown NASA Johnson Space Center Houston, Texas	Mr. David Kaplan NASA Johnson Space Center Houston, Texas
Ms. Nancy Ann Budden NASA Johnson Space Center Houston, Texas	Dr. Paul Keaton Los Alamos National Laboratory Los Alamos, New Mexico
Ms. Beth Caplan NASA Johnson Space Center Houston, Texas	Mr. Darrell Kendrick NASA Johnson Space Center Houston, Texas
Mr. John Connolly NASA Johnson Space Center Houston, Texas	Ms. Barbara Pearson NASA Johnson Space Center Houston, Texas
Dr. Michael Duke NASA Johnson Space Center Houston, Texas	Mr. Barney Roberts NASA Johnson Space Center Houston, Texas
Dr. Steve Hawley NASA Johnson Space Center Houston, Texas	Mr. Ed Svrcek NASA Johnson Space Center Houston, Texas
Mr. William Huber NASA Marshall Space Flight Center Huntsville, Alabama	Mr. David Weaver NASA Johnson Space Center Houston, Texas

- Human Evolution – Mars is the most accessible planetary body beyond the Earth-Moon system where sustained human presence is believed to be possible. The technical objectives of Mars exploration should be to understand what would be required to sustain a permanent human presence beyond Earth. However, it is not an objective of the Reference Mission to settle Mars but to establish the feasibility of, and the technological basis for, human settlement of that planet.

- Comparative Planetology – The scientific objectives of Mars exploration should be to understand the planet and its history to better understand Earth.
- International Cooperation – The political environment at the end of the Cold War may be conducive to a concerted international effort that is appropriate, and may be required, for a sustained program.
- Technology Advancement – The human exploration of Mars currently lies at the ragged edge of achievability. Some of the technology required to achieve this mission is either available or on the horizon. Other technologies will be pulled into being by the needs of this mission. The new technologies or the new uses of existing technologies will not only benefit humans exploring Mars but will also enhance the lives of people on Earth.
- Inspiration – The goals of Mars exploration are bold, are grand, and stretch the imagination. Such goals will challenge the collective skill of the populace mobilized to accomplish this feat, will motivate our youth, will drive technical education goals, and will excite the people and nations of the world.
- Investment – In comparison with other classes of societal expenditures, the cost of a Mars exploration program is modest.

The workshop attendees then translated these elements into two specific mission objectives. For the first human exploration of Mars:

- A better understanding is needed of Mars—the planet, its history, and its current state. And to answer, as best as possible, the scientific questions that exist at the time of the exploration, a better understanding of the evolution of Mars' climate and the search for past life are pressing issues.
- It is important to demonstrate that Mars is a suitable location for longer term human exploration and settlement.

The following sections discuss the details of the science and exploration rationale as applied to the Reference Mission. Implementation details are in Section 3.

2.3 Science Rationale

Mars is an intriguing planet in part for what it can tell us about the origin and history of planets and of life. Visible to the ancients and distinctly reddish in the night sky, it has always been an attractive subject for imaginative science fiction. As the capability for space exploration grew in the 1960s, it became clear that, unlike Earth, Mars is not a planet teeming with life and has a harsh environment. The images of Mariner 4 showed a Moon-like terrain dominated by large impact craters (Figure 2-1).

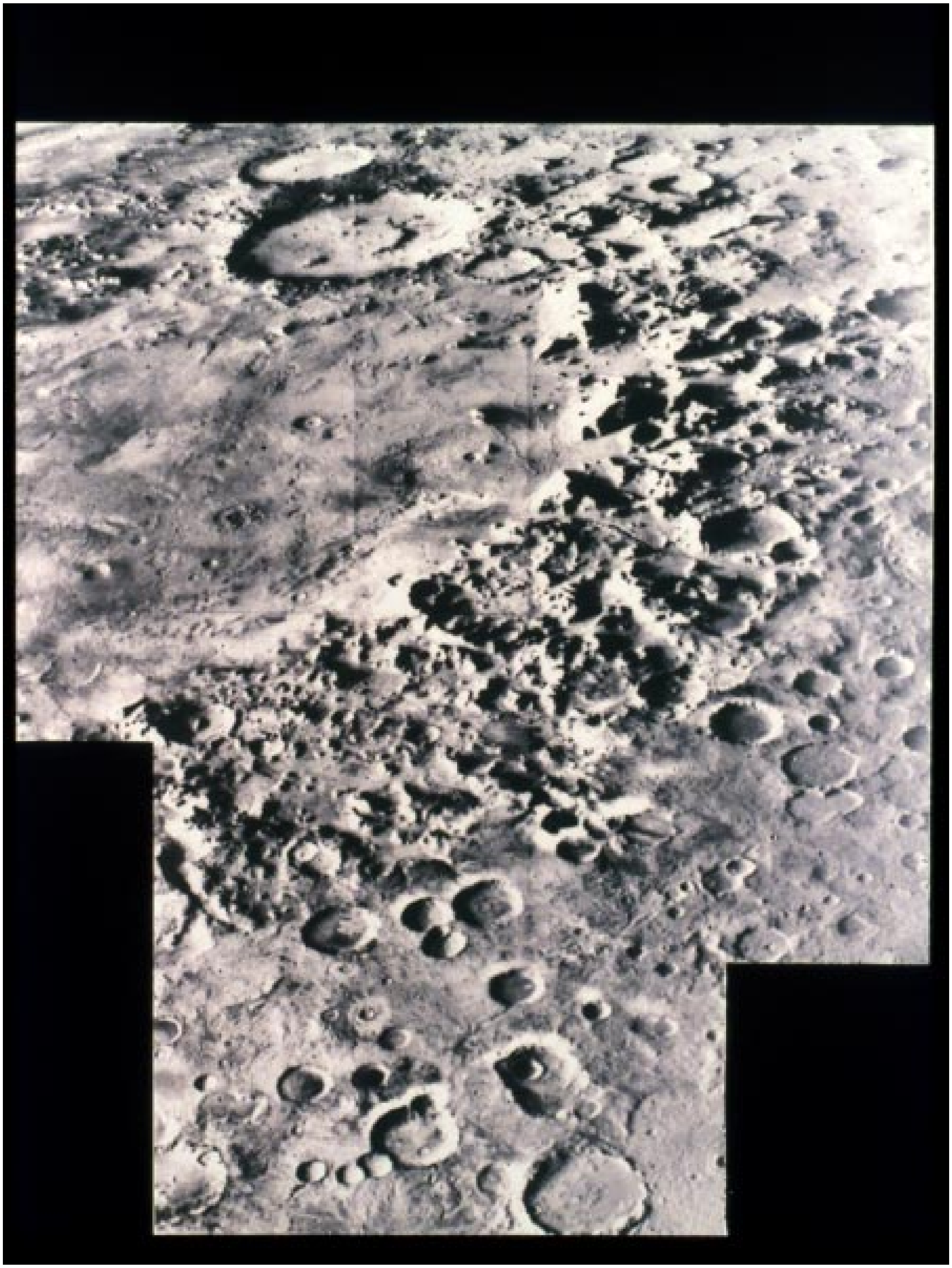

Figure 2-1 Orbital image of Mars.

This terrain now is believed to represent ancient crust, similar to the Moon's, formed in an initial period of planetary differentiation. Mariner 9 showed for the first time that Mars was not totally Moon-like, but actually exhibits later volcanic and tectonic features. Large volcanoes of relatively recent activity (Figure 2-2) and large crustal rifts due to tensional forces (Figure 2-3) demonstrate the working of internal forces.

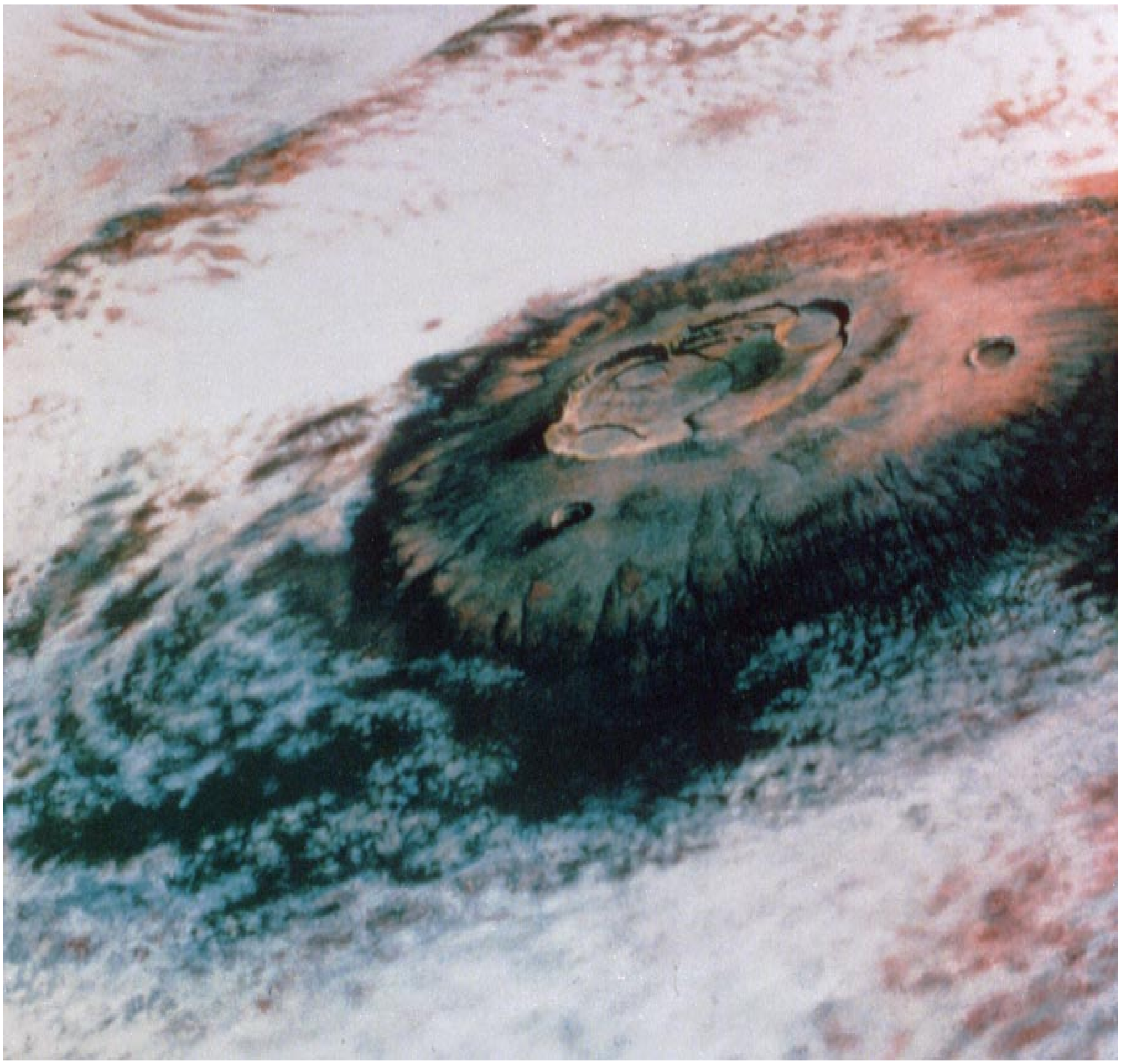

Figure 2-2 Olympus Mons, the largest volcano in the solar system.

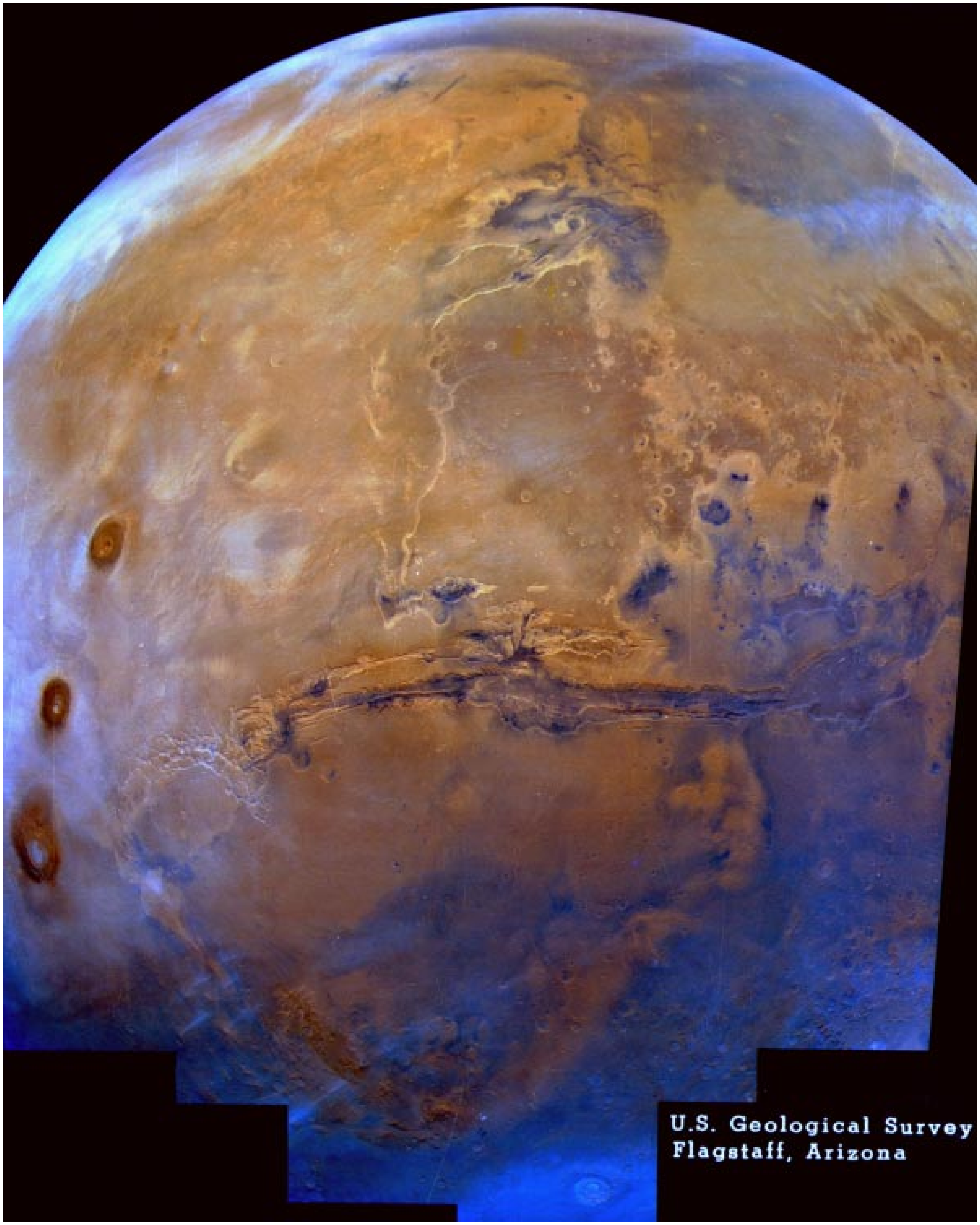

Figure 2-3 Across the middle is Valles Marineris, a huge canyon as long as the United States.

The absolute time scale is not accurately calibrated; however, by analogy with the Moon, the initial crustal formation may have occurred between 4 billion and 4.5 billion years ago, and the apparent freshness of the large martian volcanoes suggests their formation within the last billion years.

Many scientific questions exist regarding Mars and its history and will continue to exist long after the first human missions to the planet have been achieved. Two key areas of scientific interest are the evolution of martian climate and the possible existence of past life.

Mars' atmosphere now consists largely of carbon dioxide with a typical surface pressure of about 0.01 of Earth's atmosphere (comparable to Earth's atmospheric pressure at an altitude of approximately 30,000 meters or 100,000 feet) and surface temperatures that may reach 25°C (77°F) at the equator in midsummer, but are generally much colder. At these pressures and temperatures, water cannot exist in liquid form on the surface. However, Mariner 9 and the subsequent Viking missions observed features which indicate that liquid water has been present on Mars in past epochs (Figure 2-4).

Evidence for the past existence of running water and standing water has been noted, and the interpretation is that the atmosphere of Mars was thicker and warmer—perhaps much like Earth's early atmosphere before the appearance of oxygen. Three questions arise:

- What was the reason for the change of atmospheric conditions on Mars?
- What are the implications of such changes for environmental changes on Earth?
- Were the conditions on early Mars enough like those of early Earth to guide a search for past life?

These questions are part of the Mars scientific exploration addressed by the Reference Mission, and these questions can be answered only by understanding the geological attributes of the planet: the types of rocks present, the absolute and relative ages of the rocks, the distribution of subsurface water, the history of volcanic activity, the distribution of life-forming elements and compounds, and other geologic features. These attributes all have to be understood in the context of what we know about the Earth, the Moon, and other bodies of our solar system.

Addressing the question of whether life ever arose on Mars can provide a fundamental framework for an exploration strategy because, in principle, the search for past life includes investigating the geological and atmospheric evolution of the planet. It is generally understood that the search for evidence of past life cannot be conducted simply by a hit-and-miss landing-and-looking strategy, but must be undertaken in a step-wise manner in which geological provenances that might be suitable are characterized, located, and studied (Exobiology Program Office, 1995). The characteristics of suitable exploration sites are highly correlated with the search for past or present water on the

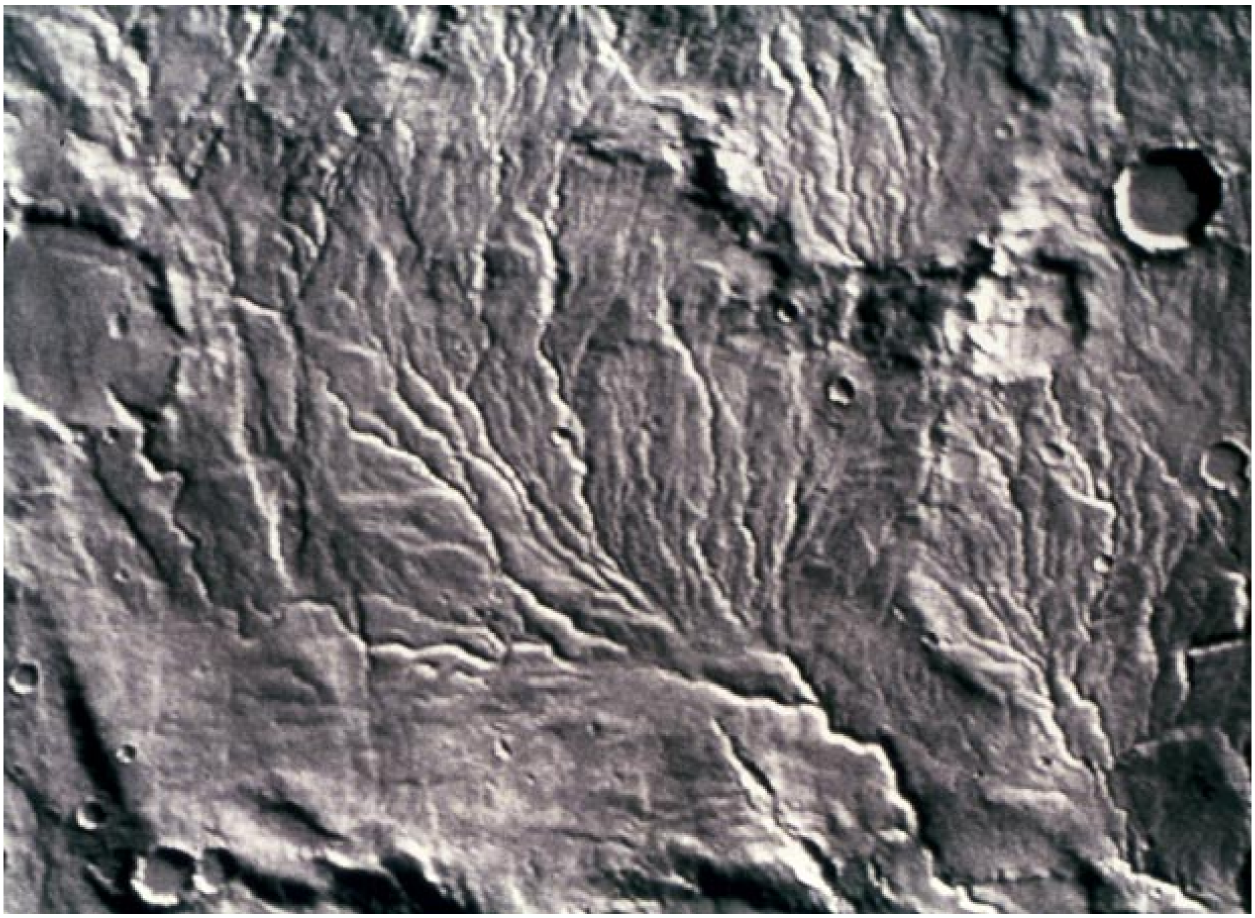

Figure 2-4 Dense tributary networks indicative of past presence of liquid water on Mars.

planet. Within the geological framework, strategic questions related to the search for evidence of life can be posed.

- What is the absolute time scale for development of the major features on Mars? This would include determining the time of formation of the martian crust, a range of formation ages for volcanic plains, and the age of the youngest volcanoes. With this information as a guide, the age of formation of water-formed channels should be boundable, and the organogenic element content of martian materials as a function of time may be obtainable. As is inferred from the SNC meteorites which are believed to have originated on Mars (Bogard, et al., 1983 and McSween, 1994), impacts on Mars have preserved samples of the martian atmosphere in shock-produced glasses. Thus, it may be possible to characterize the evolution of the atmosphere from carefully selected samples of impact glass.

- What is the evidence for the distribution in space and time of water on the surface? This would include water combined in widely distributed igneous or clay minerals, in localized deposits such as hydrothermal vents, in subsurface permafrost, in the polar caps, and in the atmosphere. The distribution, age, composition, and mode of formation (minerals formed by reaction with or deposition from heated or cool aqueous fluids, as found in the SNC meteorites) is of major interest. Can the channels apparently formed by water erosion be demonstrated to have experienced running water? Is there verifiable evidence for the existence of ponds of water? What is the distribution of subsurface permafrost, and can the features interpreted as permafrost collapse be verified?

- What are the distribution and characteristics of carbon and nitrogen—the organogenic elements? Where do they exist in reduced form? In what environments are they preserved in their original state? Is there chemical, isotopic (hydrogen, carbon, nitrogen isotopes), or morphological evidence that will link concentrations of organogenic elements to the past existence of life?

- If organic remains can be found, how extensive are they in space and time? What are their characteristics, variety and complexity? How are they similar or different to biological materials on Earth?

Answers to these questions may be sought through orbital mapping (for example, to determine the distribution of hydrothermal mineral deposits), in situ studies (surface mineralogy, distribution of volatile elements), sample return (age of rock units, detailed chemistry, mineralogy, and isotopic composition), and human exploration with sample return (similar but with more highly intelligent sample collection). The scientific community debates the precise order of investigative means used to achieve this strategy, but generally concludes that the question of distribution of past life will be of such a difficult nature that sample return will be required and that humans will ultimately choose to carry out the exploration in person.

Given the assumption that humans will take on the bulk of this type of exploration, the key questions become:

- What is the appropriate role and place in the exploration strategy of robotic sample return missions?
- Scientifically, where is the appropriate transition from robotic missions, conducted routinely, and human exploration missions, which may be singular, large, and not reproducible?

General guidelines are needed to answer these questions. Sample return missions should be favored when they can be used to significantly reduce the number of subsequent missions to address the geological modeling of the planet. Sample return missions are likely to be more expensive than one-way missions, so to be cost effective, they must reduce the need for a proportionally larger number of subsequent missions or garner otherwise unobtainable information if their justification is purely scientific. From a scientific perspective, the guidelines for human exploration are similar. If a human exploration mission promises to answer the major strategic questions better than a larger number of robotic explorers, or opens new modes of exploration that cannot be achieved robotically, then the human mission will be cost effective on scientific grounds.

2.4 Exploration Rationale

Aside from purely scientific benefits, the human exploration of Mars brings with it many tangible and intangible near-term benefits such as:

- New associations between groups or disciplines which previously have not interacted, but because of common objectives in exploration find new strengths and opportunities (for example, new international cooperation).
- New technologies which may be used for practical application on Earth or in other space enterprises (dual-use technologies).
- Education of a new generation of engineers and scientists spurred by the dream of Mars exploration.

In the long term, the biggest benefit of the human exploration of Mars may well be the philosophical and practical implications of settling another planet.

2.4.1 Inhabiting Another Planet

The dream of human exploration of Mars is intimately tied to the belief that new lands create new opportunities and prosperity. In human history, migrations of people have been stimulated by overcrowding, exhaustion of resources, the search for religious or economic freedom, competitive advantage, and other human concerns. Rarely have humans entered new territory and then completely abandoned it. A few people have always been adventurous enough to adopt a newly found territory as their home. Most of the settlements have eventually become economically self-sufficient and have enlarged the genetic and economic diversity of humanity. The technological revolution of the twentieth century, with high speed communication and transportation and integrated economic activity, may have reversed the trend toward human diversity; however, settlement of the planets can once again enlarge the sphere of human action and life.

Outside the area of fundamental science, the possibility that Mars might someday be a home for humans is at the core of much of the popular interest in Mars exploration. A human settlement on Mars, which would have to be self-sufficient to be sustainable, would satisfy human urges to challenge the limits of human capability, create the potential for saving human civilization from an ecological disaster on Earth (for example, a giant asteroid impact or a nuclear incident), and potentially lead to a new range of human endeavors that are not attainable on Earth.

The settlement of Mars presents new problems and challenges. The absence of a natural environment that humans and most terrestrial fauna and flora would find livable and the current high cost of transportation are the main barriers to human expansion there. The fact that, once on Mars, humans cannot easily return to the Earth (and then only at specified times approximately 26 months apart) makes it necessary to develop systems with high reliability and robustness.

At the present level of human technological capability, a self-sufficient settlement on Mars stretches our technical limits and is not economically justifiable, but it is imaginable. If, however, transportation costs were to be reduced by two orders of magnitude, such settlements might become economically feasible. What kind of strategy should be followed to explore the concept of humans permanently inhabiting Mars? Three considerations are important.

- Demonstrating the potential for self-sufficiency. This would include understanding the potential to obtain all important materials to support human habitation from the natural materials of Mars. It is most important that humans be able to capture energy for driving processes and have access to natural resources (such as water, oxygen, agricultural raw materials, building materials, and industrial materials) from martian rocks and soil. Demonstrating self-sufficiency requires that resources be located and technology and experience be developed to efficiently extract them from the in situ materials. Much can be done robotically to locate resources prior to arrival of the first human crew. Extraction technology depends on a more detailed understanding of the specific materials present on Mars and requires the detailed mineralogical and chemical analyses generally associated with sample return missions. An exception is the production of water, methane, and oxygen from the martian atmosphere, which is now known well enough to design extraction technology (Sullivan, et al., 1995). In addition to the extraction and use of martian resources, self-sufficiency undoubtedly requires highly advanced life support systems in which most of the waste product from human activity is recovered and reused, and food is grown on the planet.

- Demonstrating that human beings can survive and flourish on Mars. This will likely be first explored by long-duration missions in Earth orbit and may be continued in the 1/6-g environment of the Moon (Synthesis Group, 1991). Two types of needs—physical and psychological—must be met for humans to survive and flourish on Mars. Physical needs will be met through advanced life support systems, preventive medical sciences (nutrition, exercise, environmental control, etc.), and the capability of medical support for people on Mars. Psychological needs will be met through the design of systems, identification and selection of work for crews, communications with Earth, and a better understanding of human interactions in small communities. Many of these can be addressed through a lunar outpost program or in the International Space Station program to be conducted in the late 1990s. Some of these concerns can also be addressed on the first human exploration missions to Mars, in which greater risks may be taken than are appropriate for later settlement.

- Demonstrating that the risks to survival faced in the daily life of settlers on Mars are compatible with the benefits perceived by the settlers. Risks to survival can be quantified through the Mars exploration program. However, the benefits will be those perceived by future generations and cannot be addressed here.

2.4.2 International Cooperation

The space age gained its start in a period of intense technical and social competition between East and West, represented by the Soviet Union and the United States. Competition during the International Geophysical Year resulted in the Soviet Union being the first to launch a satellite into Earth orbit, which served to challenge and remind the United States that technological supremacy was not solely the province of the United States.

The start of the Apollo program was a political decision based more on the perception of the political and technological rewards to be gained by attacking a truly difficult objective in a constrained time period. The space race began, the United States won it, and a relatively few years later, the Soviet Union collapsed. Fortunately, the Russians did not view Apollo success as a reason to terminate their space exploration program, and they continued to develop capabilities that are in many areas on a par with United States capabilities. Also, during the post-Apollo time frame, space capability grew in Europe (with the formation of the European Space Agency), Japan, Canada, China, and other countries. With these developments, the basis has been laid for a truly international approach to Mars exploration—an objective in which all humanity can share.

The exploration of Mars will derive significant nontechnical benefits from structuring this undertaking as an international enterprise. It is unnecessary for any country to undertake human exploration of Mars alone, particularly when others, who may not now have the required magnitude of capability or financial resources, do have the technological know-how. An underlying requirement for the Reference Mission is that it be implemented by a multinational group of nations and explorers. This would allow for a continuation of the cooperative effort that is being made to develop, launch, and operate the International Space Station.

2.4.3 Technological Advancement

From the outset, the Reference Mission was not envisioned to be a technology development program. The Mars Study Team made a deliberate effort to use either technology concepts that are in use today or basic concepts that are well understood. Section 3 of this report will illustrate that much of the technology needed for a Mars mission is either currently available or within the experience base of the spacefaring nations of the Earth. No fundamental breakthroughs are required to accomplish the mission. However, an extended period of advanced development will be required to prepare the systems needed to travel to and from Mars or to operate on the surface of Mars; specifically, high efficiency propulsion systems, life support systems, and an advanced degree of automation to operate, and if necessary repair, processing equipment. At a general level, perhaps two of the most important ways in which the Reference Mission will help advance technology that will benefit more than just this program is to provide the programmatic “pull” to bring technologies to a usable state and the “drive” to make systems smaller, lighter, and more efficient for a reasonable cost.

For any of the technology areas mentioned above (as well as others not mentioned), this program will require systems using these technologies to meet performance specifications and be delivered on schedule, all at a pace perhaps not otherwise required. This applies to any development effort. But for the Reference Mission, many technologies will need to be ready at once, causing many of these systems to advance in maturity much faster than might have otherwise been possible. These mature systems and related technologies will then be available to the marketplace to be used in applications limited only by the imagination of entrepreneurs.

The matured systems and the technologies behind them will be attractive to entrepreneurs in part because of the effort to make them smaller, lighter, and more efficient. A kilogram of mass saved in any of these systems saves many tens of kilograms of mass at launch from Earth (depending on the propulsion system used) simply because less propellant is required to move the systems from Earth to Mars. Smaller, lighter, or more efficient each translate into a competitive advantage in the marketplace for those who use these technologies.

Among the specific areas of desirable technology advancement is propulsion systems. Even the earliest studies for sending people to the Moon or Mars recognized that propulsion system efficiency improvements have tremendous leverage in reducing the size of the complete transportation system needed to move people and supplies. Chemical propulsion systems are reaching the theoretical limits of efficiency in the rocket engines now being produced. Further improvements in efficiency will require the use of nuclear or electrical propulsion concepts which have the potential of improving propulsion efficiencies by a factor of up to 10, with corresponding reductions in the amount of propellant needed to move payload from one place to another. Both of these propulsion technologies have matured to a relatively high state of readiness in the past, but neither has reached the level necessary to be used on the Reference Mission. Once developed, these technologies become available for use, perhaps on reusable vehicles, for the ever-increasing traffic in LEO up to geosynchronous altitude.

Another area of tremendous leverage for a mission to other planets is the ability to use resources already there rather than burdening the transportation system by bringing them from Earth. Focusing on understanding what is required for eventual settlement on Mars leads quickly to those technologies that allow the crew to live off the land. Of the known raw materials available on Mars, the atmosphere can be found everywhere and can be used as feedstock to produce propellants and life support resources. Other raw materials (such as water) will eventually be found and used, but sufficient detail is not currently known about their locations and quantities. This is an objective for initial exploration.

Much of the processing technology needed to produce propellants from atmospheric gases already exists and is in use on Earth. However, integrating these technologies into a production plant that can operate unattended for a period of years, including self-repair, is an area where additional development effort will be required. (Chemical processing plants on Earth are making significant progress toward autonomous operation even now.) In this area, the Reference Mission will adapt the existing technologies at the time of the Reference Mission rather than pull those technologies up to the levels needed by the program. Regardless of how this technology is developed, the advantages in manufacturing and materials processing will be significant.

Life support systems is another specific area where advancing the state of the art can significantly reduce the overall size of the systems launched from Earth. The same technologies that produce propellants can also produce water and breathable gases for human crews. These resources can be used as makeup for losses in a closed or partially closed life support system, and can also serve as an emergency cache should primary life support weaken or fail. Life support for this Reference Mission can take advantage of developments already made for International Space Station and submarine use. Developments in support of the Reference Mission are likely to return technologies that are smaller, more efficient, and perhaps less costly than those available at the time.

Important in all of these areas is a focus on ensuring that the cost to manufacture and operate these systems is affordable in the current economic environment. The design-to-cost concept is not currently well understood in the aerospace industry, and any advancements in this area will benefit development programs well beyond those connected with the Reference Mission. Developing the tools needed to determine costs that are as easy to use as the tools used to predict system performance is one of the key technology areas that will help make the Reference Mission possible. Equal with this is instilling an attitude of cost consciousness in the engineering community that will design and produce these systems. The importance of cost as a design consideration and providing the tools to accurately forecast cost should be incorporated in the educational system that trains these engineers.

2.4.4 Inspiration

It can be argued that one role of government is to serve as a focusing agent for those events in history that motivate and unify groups of people to achieve a common purpose. Reacting to conflicts quickly comes to mind as an example. For the United States, World War II and the Persian Gulf War are examples of how a nation was unified in a positive sense; the Viet Nam War is an example of how the opposite occurred.

It can also be argued that a role of government is to undertake technical and engineering projects that can inspire and challenge. The great dam building projects in the American West during the 1930s is an example of the government marshaling the resources to harness vast river systems for electrical power and irrigation to allow for population growth. The Interstate Highway System is another example that receives little fanfare but has changed the way we live. The government incentives to private entities that led to the development of the vast intercontinental rail system in the last century is another example.

Few government efforts can collectively motivate, unify, challenge, and inspire. The Apollo program was one such example that focused a national need to compete with another nation in a very visible and high profile manner; the Reference Mission can serve as another. In this instance, the undertaking provides a focus for the human need to struggle and compete to achieve a worthy goal—not by competing against each other but rather against the challenges presented by a common goal.

2.4.5 Investment

Scientific investigation, human expansion, technology advancement, and inspiration are not attainable free of charge. Resources must be devoted to such a project for it to succeed; and at a certain level, this can be viewed as denying those resources to other worthy goals. The Reference Mission costs are high by current space program standards, and additional effort is needed to reduce these costs. The total program and annual costs of the Reference Mission range from 1 percent to 2 percent of the current Federal budget—still far below other Federal programs. If this program expands to an international undertaking, the costs incurred by each partner would be reduced even more.

A debate must still occur to determine if this project is a worthwhile investment of the public's resources. But the use of these resources should be viewed as more than just an effort to send a few people to Mars. This project will be investing in a growing part of the infrastructure that affects our everyday life: the use of space for business, commerce, and entertainment. Just as space projects do now, the Reference Mission can serve as a focal point for invigorating the scientific, technical, and social elements of the education system, but with a much longer range vision.

2.5 Why Not Mars?

Several impediments may severely hamper the implementation of a program for the human exploration of Mars. Some impediments are due simply to the fact that they have not been evaluated in sufficient detail to gauge their impact. Others are simply beyond the control of this or any other program and must be taken into account as the program advances. The following paragraphs discuss some of these impediments as viewed by the Mars Study Team and others considering programs of this type (Mendell, 1991).

2.5.1 Human Performance

It is a known fact that the human body undergoes certain changes when exposed to extended periods of weightlessness—changes that are most debilitating when the space traveler must readapt to gravity. The most serious known changes include cardiovascular deconditioning, decreased muscle tone, loss of calcium from bone mass, and suppression of the immune system. A variety of countermeasures for these conditions have been suggested, but none have been validated through testing for long-term, zero-g spaceflight. The Russians have had some success with long periods of daily exercise to maintain cardiovascular capacity and muscle tone, but monotonous and time-consuming exercise regimes affect the efficiency and morale of the crew.

Artificial gravity is often put forward as a possible solution. In this case, the entire spacecraft, or at least that portion containing the living quarters for the crew, would be rotated so that the crew experiences a constant downward acceleration that simulates gravity. It is generally assumed that the Coriolis effect (the dizziness caused by spinning around in circles) will fall below the threshold of human perception if the spacecraft is rotated at a slow rate. It is not known whether simulation of full terrestrial gravity is required to counteract all of the known deconditioning effects of weightlessness, or whether the small residual Coriolis effect will cause some disorientation in crew members. No data from a space-based facility exists, and the space life science research community is split over the viability of artificial gravity as a solution.

Deconditioning is a critical issue for Mars missions because the crew will undergo high transient accelerations during descent to the martian surface. Depending on the physiological condition of the crew, these accelerations could be life threatening. Once on the surface of Mars, the crew must recover without external medical support and must perform a series of demanding tasks. The time required for recovery is particularly important if the surface stay is short (as has been proposed for “opposition-class” missions).

No one knows whether exposure to a gravity field lower than the Earth’s will reverse the deconditioning induced by weightless space travel. And if some level of gravity does halt the deconditioning effects, what level is too low? In other words, if a crew arrives on Mars in good physical condition, what will their condition be after spending an extended period of time under martian gravity? Artificial gravity cannot be provided easily on the martian surface, and Apollo missions to the Moon were too short to produce observable differences between the condition of the astronauts who went to the surface and those who remained weightless in orbit.

The human body’s reaction to Mars surface conditions, other than gravity, is also not yet known. The Viking missions to Mars found a highly reactive agent in the martian soil, an explanation for which has not yet been agreed to by the scientific community. Without understanding this agent’s chemical behavior, its impact on human crews cannot be determined. No matter how carefully the Mars surface systems are designed and no matter how carefully the crews handle native materials, small amounts of the martian atmosphere and soil will be introduced into crew living compartments during the course of the mission. It will be necessary to better characterize the Mars environment and assess its impact on the crew. Assuring the health and safety of the crew will be of obvious importance.

Psychiatrists and psychologists agree that piloted missions to Mars may well give rise to behavioral aberrations among the crew as have been seen on Earth in conditions of stress and isolation over long periods of time. The probability of occurrence and the level of any such anomalous behavior will depend not only on the crew members individually but also on the group dynamics among the crew and between the crew and mission support personnel on Earth. In general, the probability of behavior extreme enough to threaten the mission will decrease with an increased crew size. However, the expense of sending large payloads to Mars to support a large crew will limit the number of people in any one crew. At the present time, little effort has been spent developing techniques for crew selection that will adequately guarantee psychological stability on a voyage to Mars and back. Russian experience suggests that a crew should train together for many years prior to an extended flight.

2.5.2 System Reliability and Lifetime

The spacecraft and surface elements will likely be the most complex systems constructed up to that point in time, and the lives of the crew will depend on the reliability of those systems for at least 3 years. By comparison, a Mars mission will be of a duration at least two orders of magnitude greater than a Shuttle mission, and there will be no opportunity for resupply. Either the systems must work without failure or the crew must have adequate time and capability to repair those elements which fail.

Particularly important to the success of piloted Mars missions will be testing of integrated flight systems under conditions similar to the actual mission for periods of time similar to, and preferably much greater than, the actual mission. Integrated flight testing is truly critical if the flight system is the first of its kind. Unfortunately, if history is a guide, budget pressures will cause program management to search for substitutions for full-up flight testing. (For full-up flight testing, hardware identical to that used in flight is operated for periods of time equal to or greater than the actual mission which allows weaknesses or failures to be identified and corrected. This is the most expensive way to test, in terms of time and money.) After all, most of the expense of a mission to Mars is in launch and operations, two categories of expense for a flight test whose magnitude would be similar to that of an actual mission. And what possible motivation would there be for a crew to spend 2 or 3 years in orbit pretending to go to Mars?

Somewhere in a large, complex program, a manager will take a shortcut under pressure from budget or schedule reasons, and the consequences will not always be obvious to program management. As a result, the reliability of the product will be overestimated. And management always expresses a very human tendency to believe good news. (This can be illustrated by the change in the official estimates of the reliability of the Shuttle before and after the Challenger tragedy.) In short, significant risk is introduced when relying on a product that has not been tested in its working environment, whether it is a new car, a complex piece of software, or a spacecraft.

2.5.3 Political Viability and Social Concerns

The human exploration of Mars is likely to be undertaken for many of the reasons already cited as well as others not presented here. To a large degree, the responsibility for taking action based on these reasons is in the realm of political decision makers as opposed to commercial concerns or other spheres of influence. Thus, support for this type of program must be sustained in the political environment for a decade or more in the face of competition for the resources needed to carry it out.

Perhaps the closest analogy to a possible international Mars exploration program is the International Space Station, which has been an approved international flight program for over 10 years. During those 10 years, the configuration of the Station has changed several times and the number of and level of commitment from partners has changed significantly. Also during this time, Russia, initially a significant competitor, has turned into one of the larger partners in the endeavor. And all of this has taken place prior to launching the first element of the Station. Shortening development time can be beneficial if the project remains focused on its requirements and can avoid changes imposed by external forces.

If an institution wishes to be supported with public funds for a long-duration project, then the institution must be sophisticated enough to plan visible milestones, which are comprehensible to the public, at intervals appropriate to the funding review process. Historically, NASA has been reasonably successful at maintaining funding of decade-long programs in the face of an annual budget review. The vast majority of the programs are understood by all to have a finite duration. After a satellite has been launched and operated for a given period of time, it either fails or is shut off. Neither NASA nor the U.S. Congress are yet comfortable with open-ended programs such as the Shuttle or International Space Station or human settlement of the solar system.

The decades-long time frame for human exploration of Mars cannot be supported until the role of the space program is well integrated into the national space agenda and the exploration of space is no longer considered a subsidy of the aerospace industry. To accomplish this, the space program must show concern for national and international needs (visible contributions to technology, science, environmental studies, education, inspiration of youth, etc.) while maintaining a thoughtful and challenging agenda of human exploration of space in which the public can feel a partnership.

Finally there is the political concern of back-contamination of Earth. This is as much a social issue as a technical one. Some segments of the population will object to any Mars mission on these grounds. The two tenets of a successful defense against such opposition are to ensure that prudent steps are taken at all phases of the project to minimize risks and to demonstrate that the value of the mission is high enough to merit the residual minuscule risk.

2.6 Summary

This section has woven together several key elements of a rationale for undertaking the Reference Mission: human evolution, comparative planetology, international cooperation, technology advancement, inspiration, and investment. Several challenging aspects must be resolved before the first human crews can be sent to Mars. But the Reference Mission has a longer range view and purpose that makes these challenges worth the effort to overcome. If, at some future time, a self-sufficient settlement is established on Mars, with the capability of internal growth without massive imports from Earth, the benefit will be to the eventual descendants of the first settlers, who will have totally different lives and perspectives because of the initial investment made by their ancestors.

2.7 References

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